AECOM

DESIGN INPUTS for the STRUCTURES on the MOON

SUPPORTING
SPACE PROGRAMS
FOR 50+ YEARS

A presentation by AECOM

1 December 2021

Delivering a better world

aecom.com

PRESENTERS

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AGENDA

- AECOM introduction
- Bridging the gap exploration vs design/build
- Instrumentation & Monitoring
- Transferable experiences for structures
- Relevant cold regions experience
- Next steps and integration with other teams

AN INDUSTRY LEADER

Consistently earning high rankings

2020 *ENR* Rankings

#2 Top 500 Global Design Firm

#1 International Markets

#1 Program Management

#1 General Building

#1 Transportation

#1 Environment

#1 Airports

#3 Water

#4 Power

AECOM Snapshot

7 continents / 140+ U.S. offices

47K global / 16,000+ U.S. staff

#163 on Fortune 500

$13.2B in revenue (2020)

Top 10 Military Friendly® Company

A Fortune World's Most Admired Company

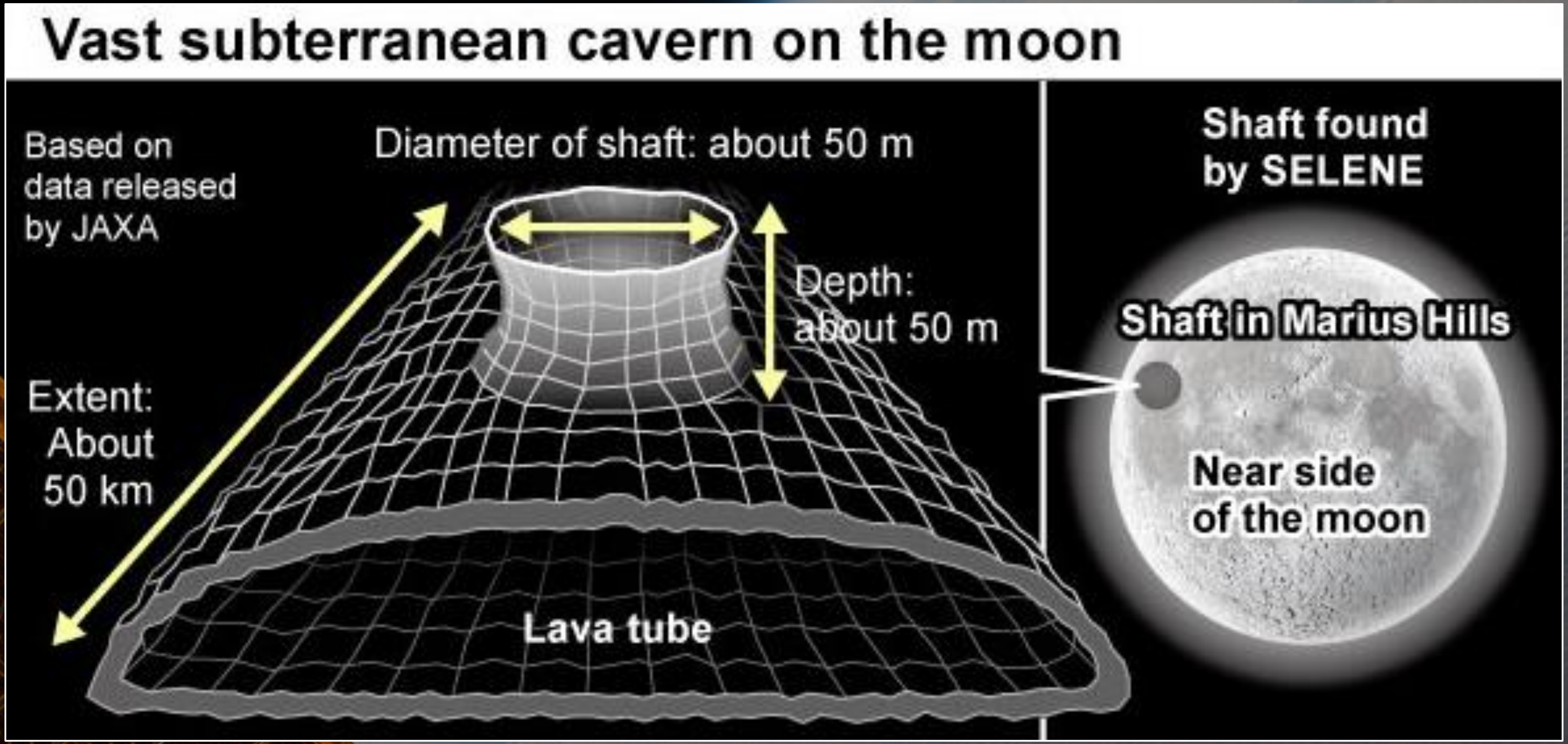
KEY CAPABILITIES

- A/E services
- Arctic & Harsh Environmental
- Asset management
- Aviation and spaceport services
- Buildings + Places
- Construction management
- Cost and schedule management
- Decommissioning and closure
- Economic impact studies
- Energy management
- Environmental services
- FAA coordination and licensing
- Facilities layout and design
- Feasibility studies
- Geophysics
- Geotechnical Engineering
- Instrumentation & monitoring
- Laboratory services
- Master planning
- Mining and Ground Improvements
- Planning and programming
- Program and project management
- Risk assessment and management
- Sustainability
- Transportation
- Tunnel Boring Machine (TBM)
- Tunnelling and underground space design

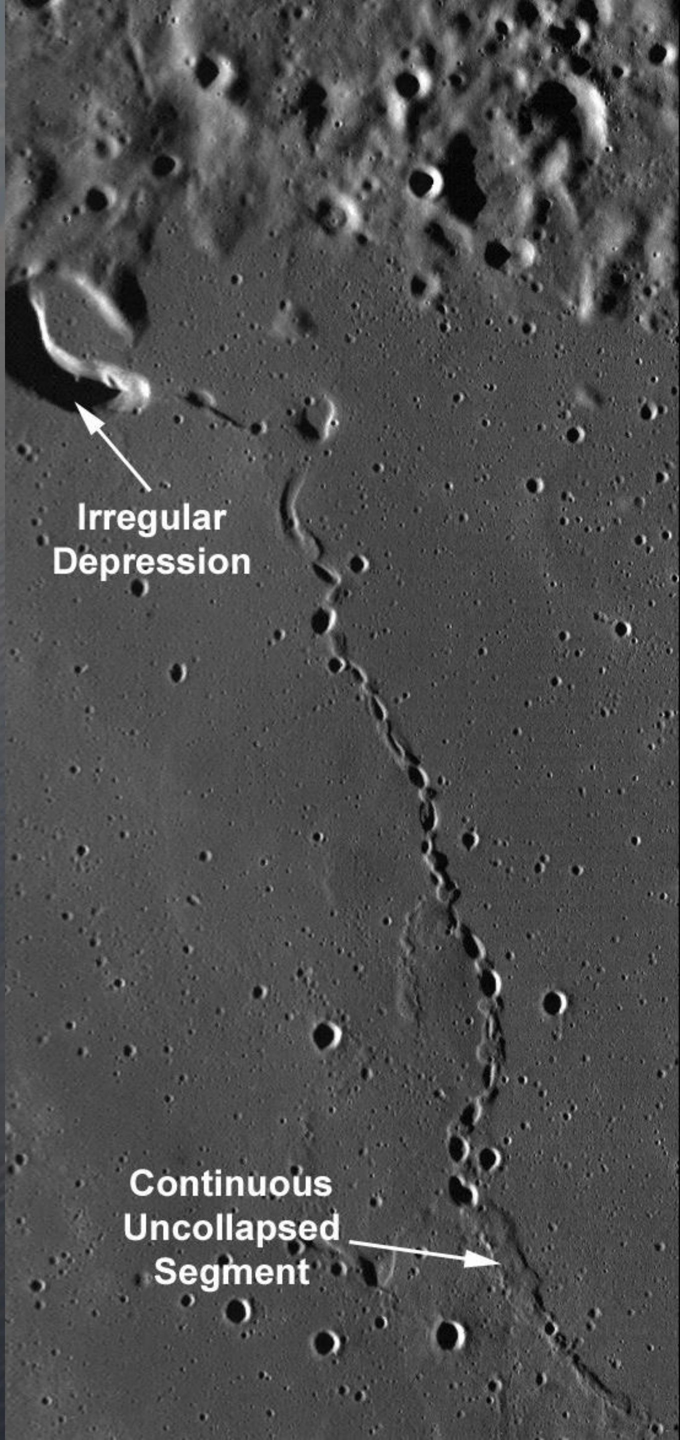
AN EXCITING FUTURE FOR MOON BUILDERS…

Credits: ICON & NASA *Project Olympus*

…AND MOON TUNNELERS TOO!



Credits: JAXA and Kaku, T. et al
(Asahi Shimbun publication)



WHAT DATA ARE WE STILL MISSING?

- ✓ On the Moon, soil mechanics information has been determined from trench excavations, vehicle tracks. Footprints, lander footpad penetrations, short rotary drillings and hand driven core samples;
- ✓ Very limited information for rock mass characterization;
- ✓ Slopes have been back analyzed to determine soil properties;
- ✓ No reliable geotechnical rock data available;
- ✓ Dead loads/live loads under lunar gravity;
- ✓ Factors of safety for the lunar conditions;
- ✓ Stability of lava tubes and other underground existing structures;
- ✓ Hydrogeological Investigations

BRIDGING THE GAP

CURRENT FOCUS

Sampling
- Surface samples
- Dust collection
- Deep coring

Transport
- Refrigerating
- Limiting disturbance
- Quantities

Testing
- Site test
- Laboratory

Are we doing the right thing?

AECOM INPUTS

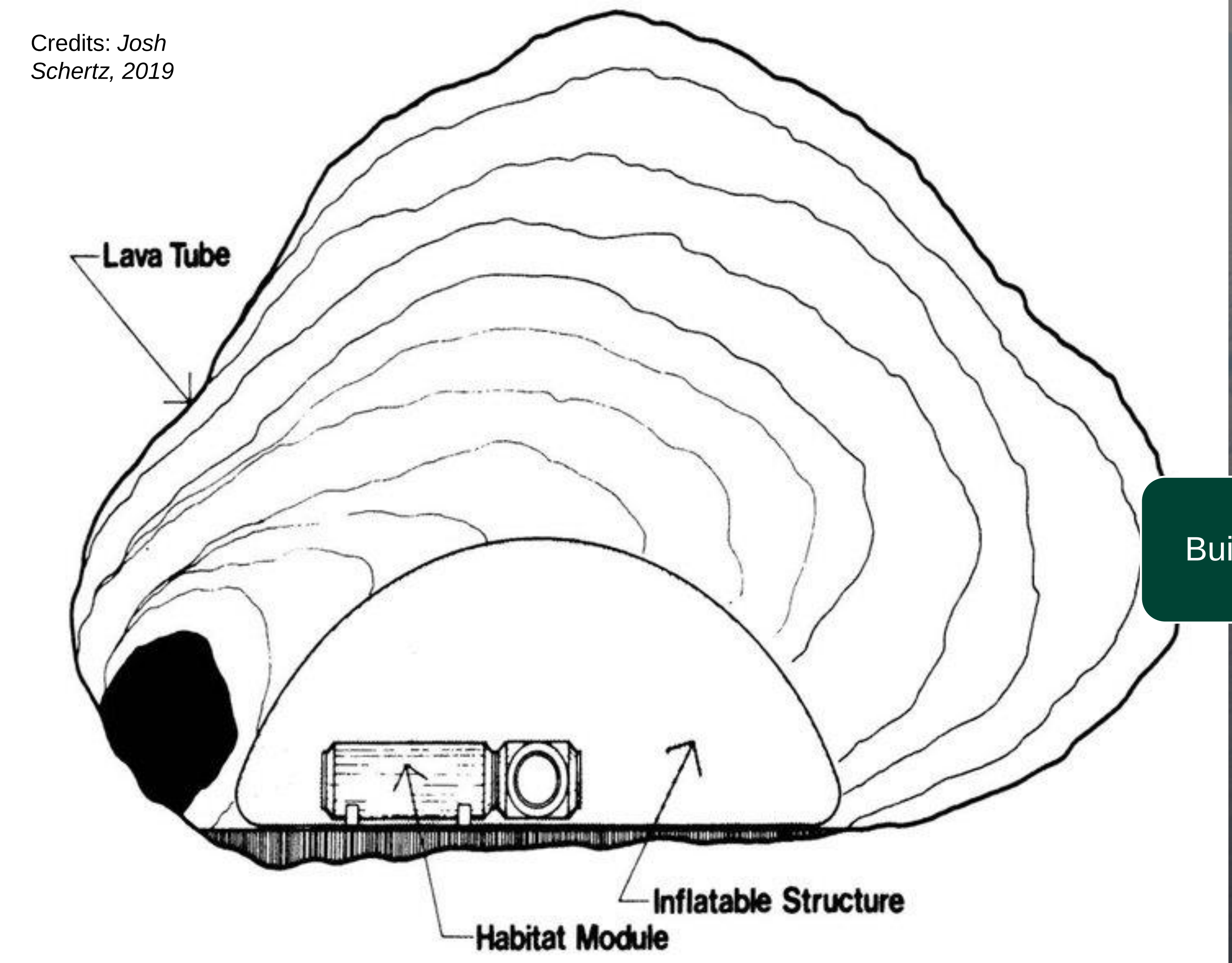
Interpreting
- Rock mass behaviour
- Ground properties

Designing
- Sequential Excavation Method
- TBM use

Building

LEVERAGING ON OUR EXPERIENCE ON EARTH

Credits: *Josh Schertz, 2019*



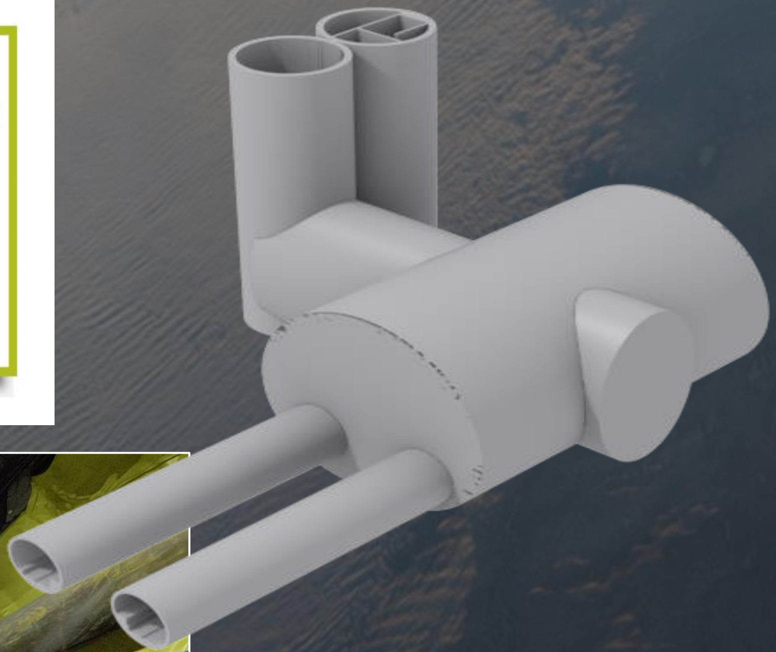
Credits: *M2P*

Building

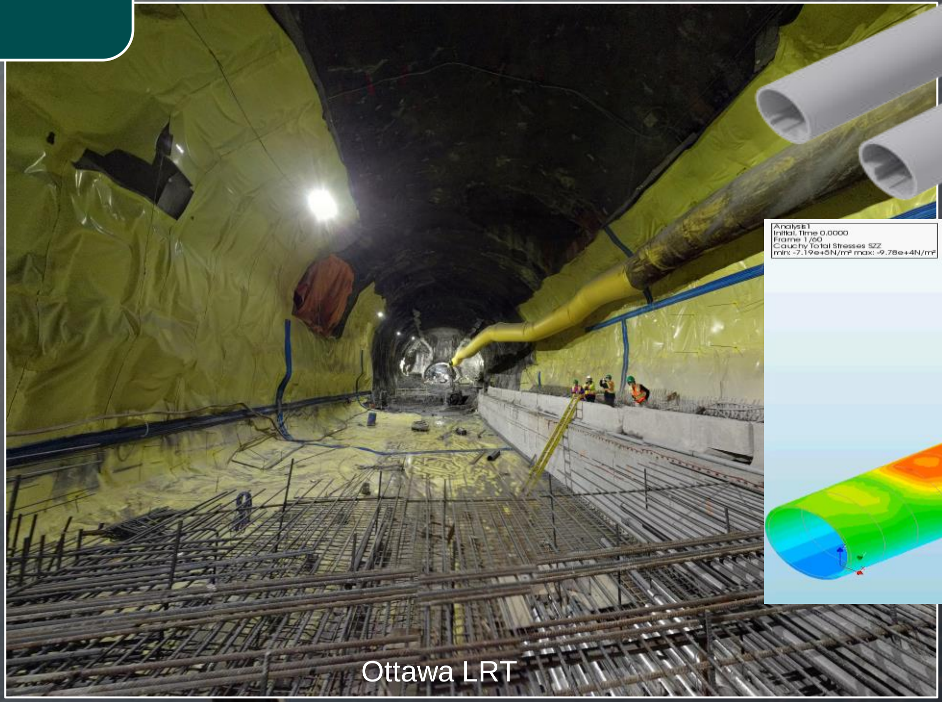
Credits: *Strata*

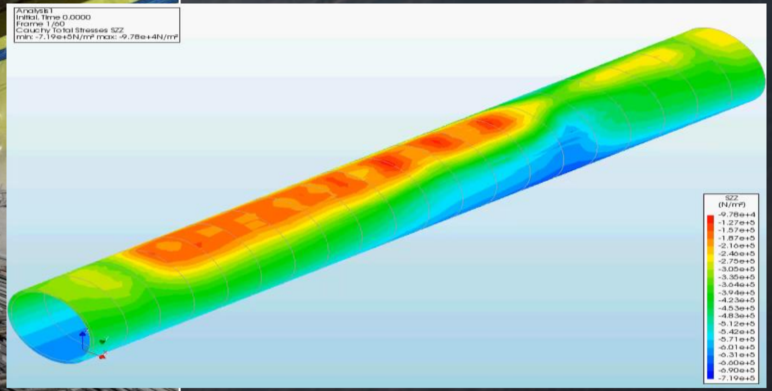
LEVERAGING ON OUR EXPERIENCE ON EARTH

Designing




Manjanggul Lava Tube – Jeju Island, South Korea


Ottawa LRT

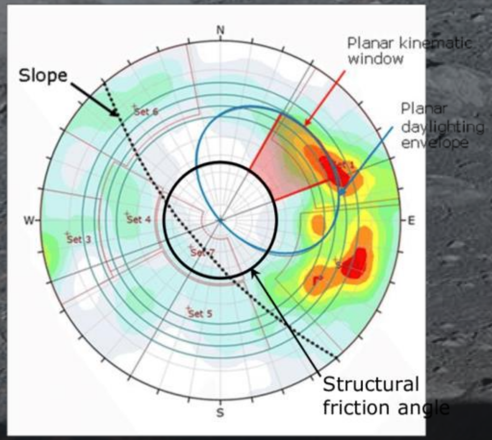


INSTRUMENTATION & MONITORING

UNCERTAINTY AND LACK OF INFORMATION CONCERNING TO THE ROCK MASS CONDITIONS

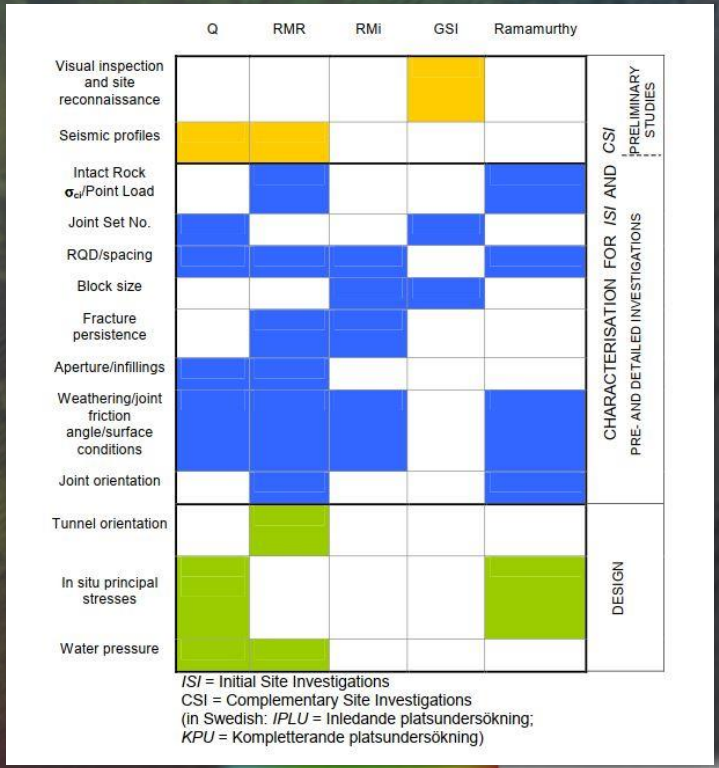
How to characterize the surface and underground rock in-situ conditions?

- Via naturally available access points: surface exposures/outcrops, caves, Valley, tectonic driven exposures (faults/), nontectonic driven features (faults/fractures), lava tubes, underground water channels, craters (meteorite-induced features);
- Engineered: borehole, wells, adits/shaft/tunnels, surface excavation/digging
- Geophysical methods: thermal, seismic, electromagnetic, electro-resistivity, magnetometry
- Geochemical methods: mineralogy, processes, age-identifiers, composition
- Geo-mapping
- Rock Mass classification via RMR, Q-system, GSI
- Remote sensing, LiDAR, InSAR, GPR



ASSUMING WE CAN APPLY THE SAME METHODS

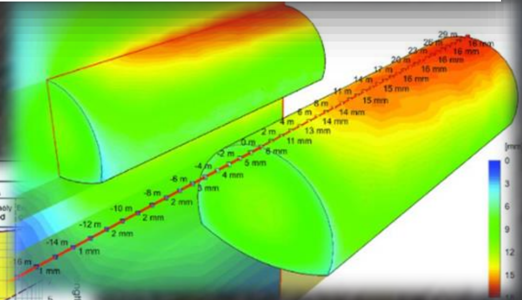
WHAT ARE THE INPUTS NEEDED?

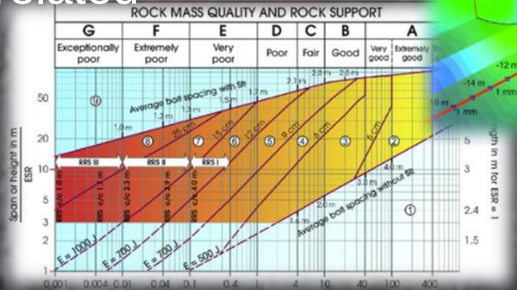


- Geotechnical characterization of lunar soils usually has been presented in terms of shear strength, shear modulus, density, and void ratio. However, no data set has been collected for the rocks and rock masses.
- Various lunar soils simulants have been developed for Earth based lunar soil studies, however, most were made from exotic materials using complex procedures.
- There are no validations for international standardized tests such as ASTM or ISRM rock testing suggestions.
- Most of the lab tests were performed in basalt fragments and basalt clasts from Apollo 16 breccia.
- No representative geotechnical rock parameters.

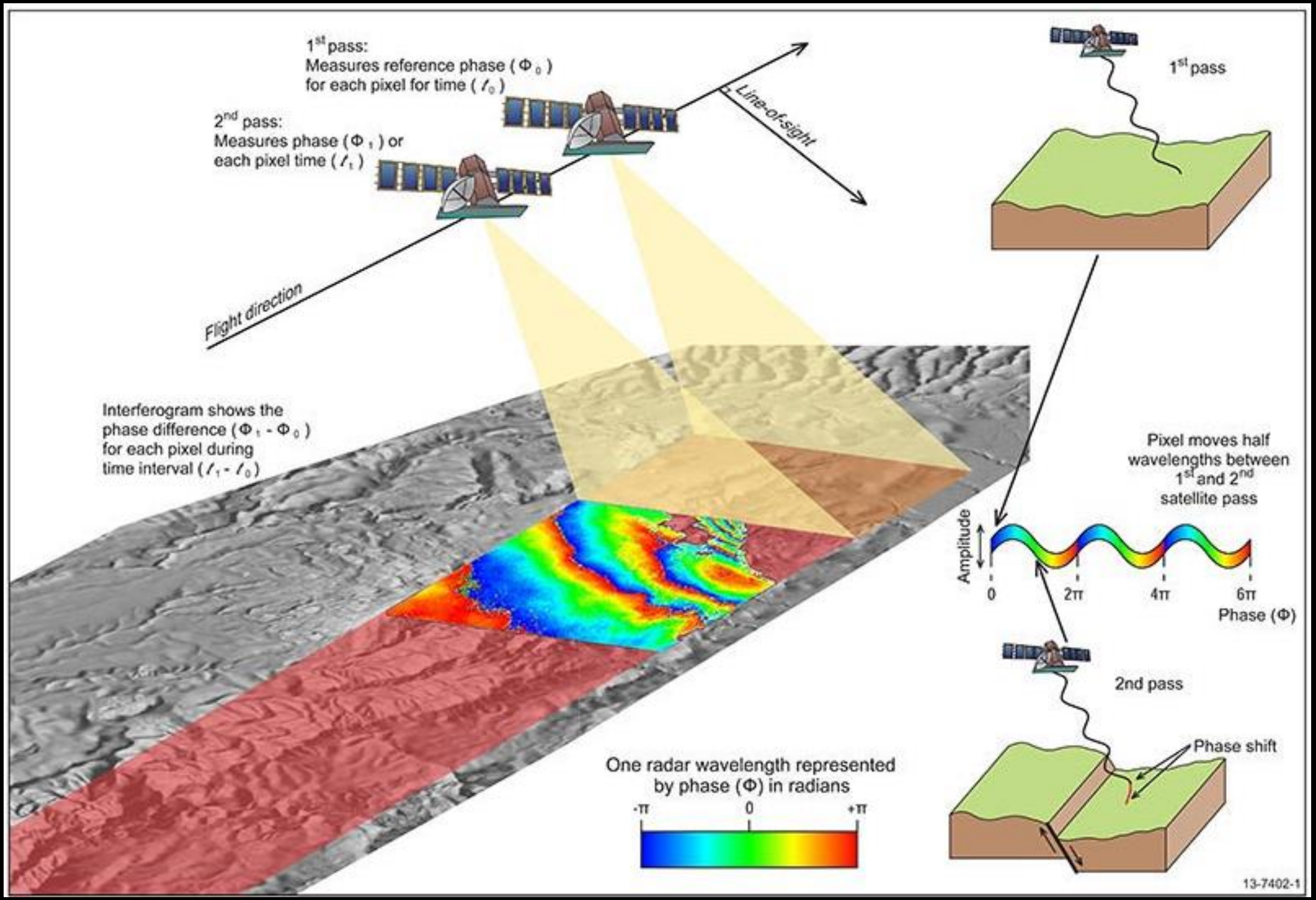
➢ Review and adapt the Rock Mass Classifications such as the Rock Mass Rating (RMR), Q-system, Geological Strength Index (GSI) and others related to soil mechanics.

➢ Most of the researches have used GSI for rock mechanics assumptions which can not be used for detail design levels.





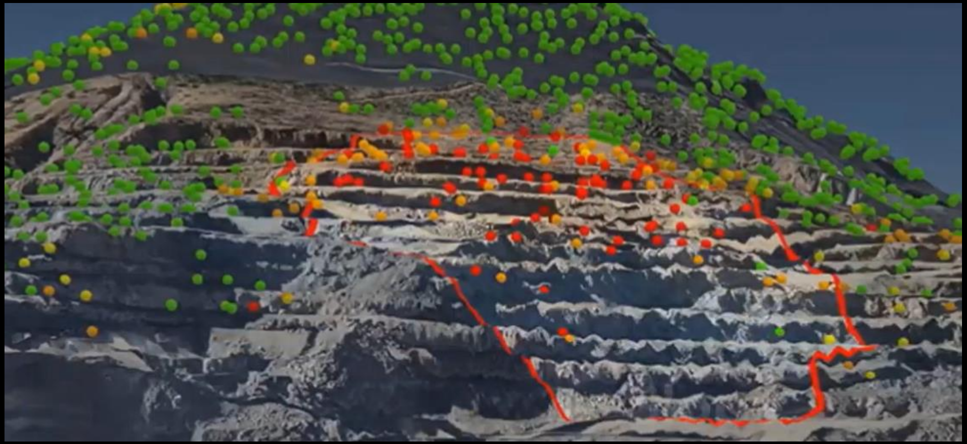
REMOTE SENSING INTERFEROMETRIC SAR – InSAR



Features

- Ground movement ranging from millimeters to meters
- All craters' assets can be monitored for ground deformation without the installation of any in-situ equipment
- An individual SAR interferogram measures deformation in one dimension, in the radar line-of-sight
- Quantitative measurement of the surface deformations induced by a variety of natural processes.
- It is an intrusive investigation.
- Can be combined with GPS/levelling measurements

REMOTE SENSING INTERFEROMETRIC SAR – InSAR Applications



Slope Stability

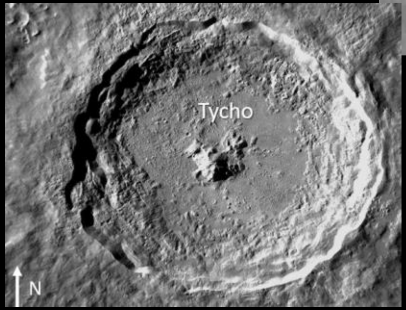
- Detects slope movements (mm-sensitivity)
- Improve risk awareness and provide early warning of impeding slope failures

Geological Mapping

- Structural geology
- Stratigraphy
- Geomorphology
- Balanced cross-section
- Water bodies
- Hazard and terrain type
- Change detection
- Vertical and Horizontal deformations

Rapid Motion Tracking

- To measure both slope and rapid surface displacement and capture the ground movement in the Lunar surface, craters' slopes, lava tubes skylights.



Limitations

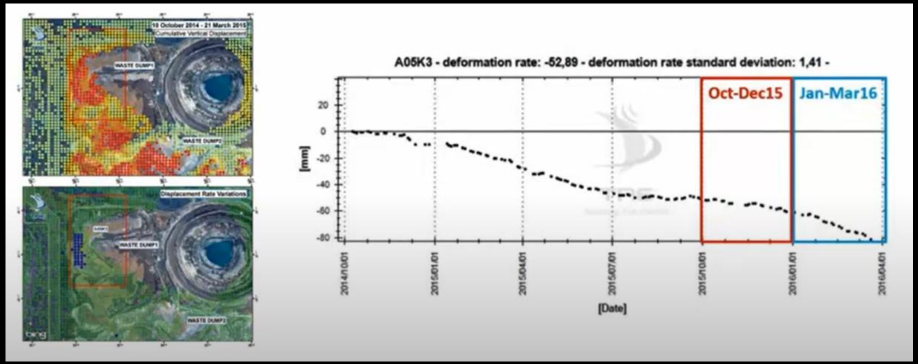
Measuring ground displacement with InSAR is a precise and efficient way to remotely monitor a large area, such as a mine site. InSAR data does have some limitations due to the nature of the data acquisition. Satellite data acquisitions are made, ideally, from a pair (ascending and descending) of orbits. Some locations may only have a single orbit available.

SATELLITE BASED TELEMETRY SYSTEM FOR InSAR MONITORING

Mining & InSAR Data Complements:

- Ground radars
- Prisms
- Piezometers
- Extracting detailed information about individual measurement points
- Use of cloud computing for processing abilities
- New researches with on AI methods
- Historical data immediately available
- Millimeter accuracy
- Can cover very large areas (1-10,000 km^2)
- Spatial resolution in the region from 3m up to 15m
- A new image is captured every 8-11 days

Movement Trends Identified Over Waste Dumps Areas



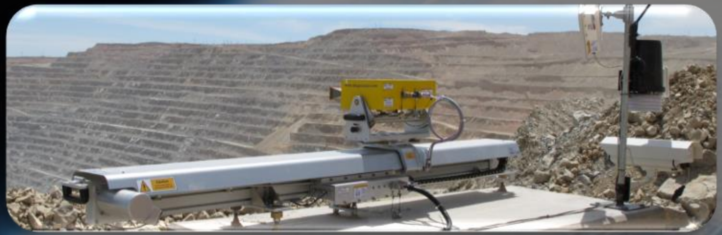
GROUND-BASED OPTIONS FOR SLOPE MONITORING (TO BE RE-ENGINEERED FOR THE MOON CONDITIONS)

Full 3D SAR Radar

FEATURES

- Scan range: up to 5000m
- Maximum coverage: 360° H x 120°V (70°V per session)
- Scan time: 360° in 40s; 180° in 20s
- Resolution: 10 million pixels for full resolution scan
- Integrated solar panels, diesel generator and optional wind turbine
- 3D SAR[1] and automatic DTM survey
- Built-in HD camera on rotating radar head (with link to radar data)
- Integrated GNSS
- Operates in all weather conditions and temperatures (-20°C/-50°C[2] to +55°C)
- Fully remote operation (wireless radio link) and optimized file size for low bandwidth
- Alarm generation with user-defined levels and multiple alarm criteria
- Zero delays in data processing and alarm generation
- Exportability of georeferenced output to mine planning software
- Built-in geotechnical analysis tools
- Integration in FPM360 TrueVector suite

SAR Radar – Static Applications



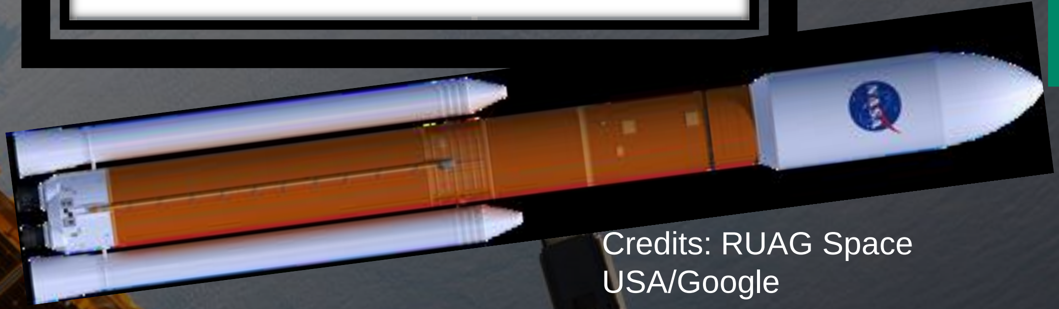
SYSTEM SPECIFICATIONS	
SPATIAL RESOLUTION*	@1 km, 0.375 m by 4.3 m @2 km, 0.375 m by 8.6 m
ACCURACY	up to 0.1 mm (Line of Sight displacement)
OPERATING RANGE*	50 m to 5.000 m
SCAN TIME	Up to 30 seconds
POWER CONSUMPTION	75-90W depending on acquisition time interval

Underground Applications

FEATURES

- Spatial coverage: horizontal field of view up to 120° and vertical of 30°
- Scan speed: a new acquisition is performed every 30 seconds
- Accuracy: line of sight displacement with an accuracy of 0.1mm
- Internal rechargeable battery pack, optional power supply options (solar, fuel cells) and line power connection
- HD camera
- Operates in all weather conditions and temperatures (-20°C to +50°C), IP65
- Alert generation with user-defined displacement, velocity and inverse velocity criteria
- Instant data processing and on-site alarm generation
- Built-in geotechnical analysis tools

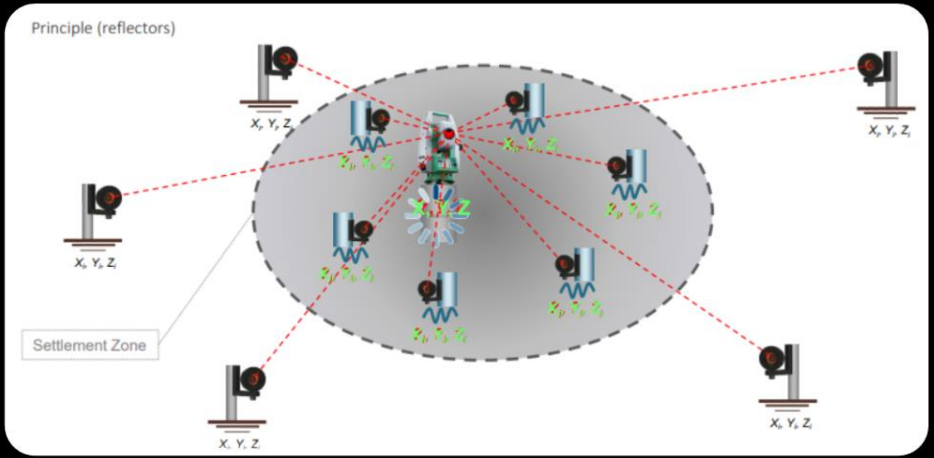
SLS Provides
130t lift capability via advanced boosters
10-meter fairings for primary payloads



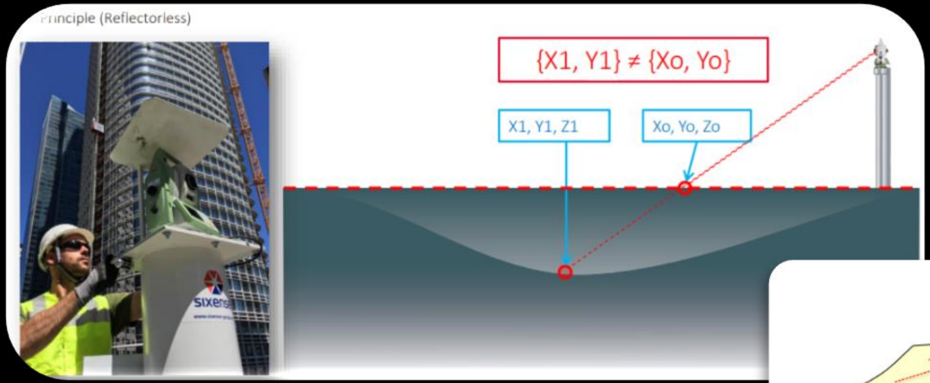
SLS Block 2
As Early As 2028

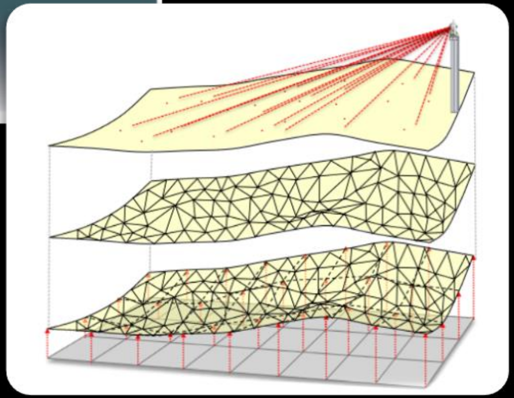
Credits: RUAG Space USA/Google

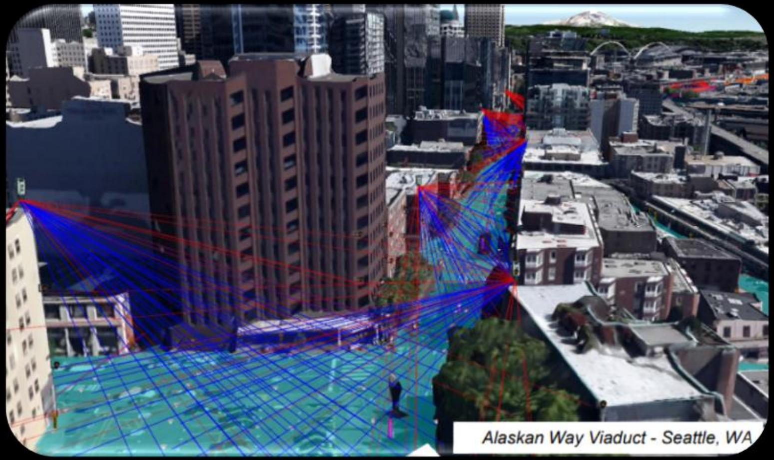
AUTOMATED MOTORIZED ROBOTIC TOTAL STATIONS (TO BE DESIGNED FOR THE MOON CONDITIONS)



	Reflectors	Reflectorless
Range	120m	60m
Accuracy	±1mm (1s)	±1.5mm (1s)
Output	X, Y, Z displacement of a point (ATR)	Vertical (Z) deformation of a surface (mesh)
Operation	Fully automated, 24/7	Fully automated, 24/7
Production	Up to 100 pts per station with hourly interval and nominal accuracy	Up to 150 pts per station with hourly interval and nominal accuracy
Applications	Buildings and adjacent structures (in/out-door), SoE and temporary structures, existing tunnels, Rail tracks, Utilities, Surfaces free of traffic (snowplow)	Road surfaces Utilities
Calibration	2 years	2 years
Imagery	Embedded camera for remote trouble shooting	Embedded camera for remote trouble shooting







AECOM UNMANNED AERIAL SYSTEM (AECOM UAS GROUP)

Drones should be driven by jets of oxygen or water vapor to move around

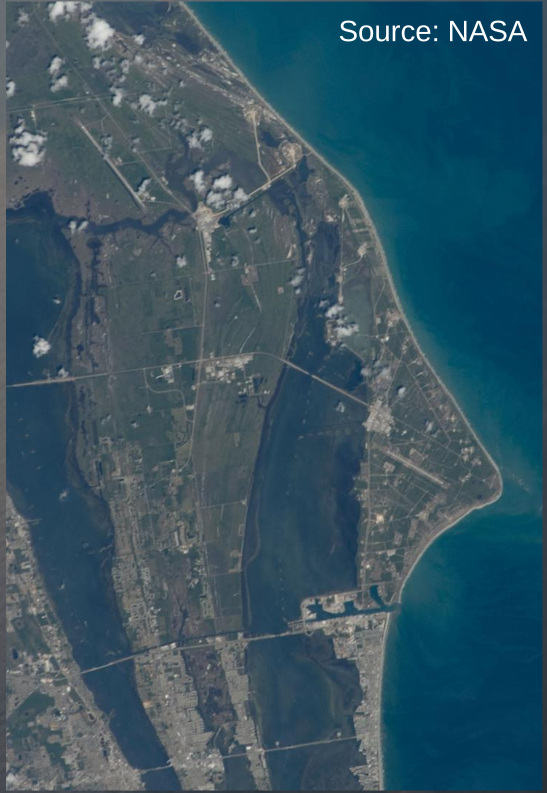
TRANSFERABLE EXPERIENCES FOR STRUCTURES

LAUNCH & LANDING PAD

Kennedy Space Center/Cape Canaveral Space Force Station: 19, 20, 36, 39A, 40, 41, & 46

- Explosive Siting
- Launch Mount
- Propellants Storage
- Control Center
- Launch Vehicle Access/Support Structures (crew vs. payload only)
- Utilities (Comm, power and propellants)
- Supporting Towers (crew access, lightning, umbilical, water)
- Flame Deflectors or flame duct
- Payload Processing
- Crew Access/emergency egress
- Access Roads
- Storm water/deluge system

SpaceX LC39A



KSC/CCSFS

Space Florida Complex 46

LANDING PAD

- Land vs. Water Barge Landing
- Typically separate from launch pad and/ safe distance away from launch pad/other facilities
- Explosive Siting
- Utilities (Comm, water, and power)
- Fire retardant concrete
- Access roads
- Boosters only vs. crew landings

SpaceX Booster Landing Pad on Land vs. Drone ship/Barge (Source SpaceX)

EARTH VS. LUNAR GROUND STABILIZATION

Type of launch vehicles/spacecrafts

- Concept of Operations
  - Launch/landing mishap
  - Hard vs. Soft Landing
  - Turn around time/delays between launches
- Materials vs. constructability
- Existing geotechnical parameters
- Protection from natural environment (comet/meteoroid strikes)
- Connectivity of Launch and Landing Pad with other habitats or facilities (underground connections or at grade?)
- Propellant storage
- Utilities: Communications (wired vs. wireless), power, and water.

- Concrete/reinforcement
- Asphalt need and 3D printing with regolith
- Admixture to strengthen subgrade or existing subsurface
- Bury utilities vs pipe/conduit vs protection to encase in concrete
- Drill shafts or piles for vertical infrastructure

Geosynthetics

There are several problems that must be considered such as:

- Plastic materials are susceptible to degradation when subjected to radiation.
- The glass transition temperature of many if not all the geosynthetics used on Earth is well above the cold temperatures that are encountered on candidate sites including that on the Moon. This would make the plastics brittle thus rendering it useless as reinforcing elements.
- There is little experience on how geosynthetics fare in a hard vacuum and respond to the relatively more abrasive regolith.

RELEVANT COLD REGIONS EXPERIENCE

Halley VI Research Station D-B, procurement, logistics and site construction for groundbreaking re-locatable structure

- → Providing Medium-Term Human Habitat in challenging conditions
- → Movable Station unique in its kind
- → Allowing research programs to be run compatible with cold weather

Halley VI Research Station

Key Features

- Highly adaptable science laboratories and stimulating areas for relaxation and recreation (medium-term base)
- Self-sufficiency heat and power, water production and waste treatment facilities
- Highly resilient services using 'plug and play' technology
- Halley VI is the first ever relocatable modular research station, providing the best scientific working and living quarters.

Halley Station Awarded Overall Global Project of the Year in ENR's Excellence Awards 2014

NEXT STEPS AND INTEGRATION WITH OTHER TEAMS

- Assessing planning needs and schedules
- Creating a list of assets and utilizations
- Program management of infrastructures
- Functional design of the human habitat
- Confirming the launch pad intermitted use
- Benchmarking with Earth and Space Labs
- Identifying the relevant H&S criteria
- Exporting Design Criteria from Earth
- Extending the use of Design Methodologies
- Defining ROI and accordingly design life

Questions and Discussions


AECOM
Delivering a
better world